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APPLICATION OF SELECTED MODELS OF MIND IN THEORIES OF PHYSICS EDUCATION

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Abstract. *In physics education research, we often focus on specific issues and rarely look at students as whole individuals. Over the past decade, researchers have explored students' bio-psycho-social aspects and analyzed the core principles of personality theories, comparing them with genetic mapping. Recently, new medical imaging techniques have been developed to scan the brain and explore the fundamental links between learning theories, incorporating psychological, social, and biological perspectives. This study offers a brief overview of selected mind theories relevant to physics education. In addition to theories and models of understanding, the primary focus is on one neurocognitive theory: the Theory of the Five Pillars of the Mind, established by Tokuhama-Espinosa. Four years of research applying this theory to physics education have produced promising results. Here, we present a preliminary study that highlights the theoretical framework of our ongoing research. The Theory of the Five Pillars of the Mind aligns well with existing physics education theories, and its application shows promising outcomes. In this contribution, we also showcase an example of how this theory can be applied.*

Keywords: *cognitive models, mind theories, physics education, preliminary study*

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Introduction

Over the past few decades, a significant body of research in physics education has focused on the theories behind the field. A part of this discussion focuses on the application of cognitive models to physics education, such as the Knowledge in Pieces model developed by diSessa (2018), the ACME model (Assessing a problem, Constructing a Model, Evaluating) developed by Sands (2021), Dual Processing theory developed by Kahneman (2012), or the Theory-Theory proposed by Morton (1980). The common fundamental underpinnings of these theories are the profound conceptual difficulties pupils face when learning even the most fundamental concepts, such as force, motion, and energy. The same epistemological foundation can be further explored via newer approaches that integrate knowledge about the brain into existing models of learning. The idea of grasping the mind, considering neurons and the brain, has its roots in 1979, when Taylor wrote his book The Natural History of the Mind (Taylor, 1979).

In this contribution, we theoretically examine cognitive models at the level of knowledge acquisition that occurs within seconds and minutes – focusing on immediate cognitive processes that influence learning. We are neither addressing learning at the molecular level nor long-term educational development. We build upon theories from cognitive science and mind, brain, and education science, and apply them to selected aspects of physics education. We especially illustrate the potential of applying such theories in designing a part of the physics curriculum. We acknowledge the contributions of 20th-century psychologists, whose findings, proven by decades of practice, were obtained despite technical limitations in experimental methodology. Nowadays, some of our colleagues possess advanced medical imaging methods for observing brain processes. Combined with a well-established theoretical background in educational theories, they can interpret the outputs of these experiments to refine the foundation upon which previous theories of physics education were developed. We appreciate the transformative model of the knowledge base for teachers and the concept of pedagogical content

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knowledge (PCK) developed by Magnusson et al. (1999). The models of mind fit the PCK well, especially in terms of PCK's knowledge (and beliefs) about instructional strategies for teaching science, and knowledge (and beliefs) about pupils' understanding of science topics (Demkanin, 2013, p.4). This study aims to expand current knowledge regarding the potential for modeling mental processes, particularly in physics education.

Research Problem

The focus of the research problem is grounded in the observation that most theories of physics education are based on cognitive and behavioral science. Although these theories vary in many aspects, they often describe similar or the same observable phenomena, suggesting the potential for conceptual overlap. There is a gap in integrating neurocognitive theories of learning with theories of physics education. Numerous theoretical studies have focused on students' conceptual difficulties in mastering even basic topics, such as motion (Estacio et al., 2024), force (Robertson et al., 2021), or energy (Heron & Snow, 2025). While these studies address observed phenomena, the underlying causes of these difficulties have received comparatively less attention. Shifting the search for the causes of such difficulties could involve applying relevant findings from neurocognitive sciences. Many professional researcher educators have published papers on applying neuroscientific findings to education in general and curriculum design specifically, such as Implications of Affective and Social Neuroscience for Educational Theory (Immordino-Yang, 2013), Neuroscience and Education: An Ideal Partnership for Producing Evidence-Based Solutions to Guide 21st Century Learning (Carew & Magsamen, 2010), and Neuroscience and Education: Issues and Challenges for Curriculum (Clement & Lovat, 2015). Elouafi, Lotfi, and Talbi (2021) experimented with four neuropedagogical methods —role-playing, the expert student, varying information access channels, and mind mapping —which resulted in a significant contribution of neuroscience to learning in teaching methods relevant to modelling of mind processes. Some neuroscientific findings are integrated into the paper Context-Based Learning for Inhibition of Alternative Conceptions: The Next Step Forward in Science Education (Renouard, Mazabraud, 2018), where authors discuss the importance of understanding the origin of individuals' conceptions, how they are acquired, and how they propagate, all within the context of science education and scientific literacy levels, on the mind background. Neurosciences, especially cognitive neuroscience, provide a strong foundation for theories behind effective learning, and their application in everyday classrooms should be more common. This idea is strongly emphasized in an analysis by Gkintoni et al. (2025), highlighting the importance of applying cognitive neuroscientific research in daily teaching. However, they suggest that teachers do not need to pursue advanced training in psychological theory or cognitive neuroscience, even though their scientific knowledge in the classroom is crucial for improving educational outcomes (Gkintoni, et al., 2025). We also see a necessity to apply new approaches to research on executive functions and special children, as well described in (Rašková, B., Hapčová, M., Celušáková, H. et al., 2025). Our effort is focused on bridging the gap between theories of physics education and a more universal theory of learning and the mind, the Theory of Five Pillars of the Mind. By identifying overlaps between cognitive theories of physics education and neurocognitive theories of learning, this study aims to propose a theoretical framework for further empirical research that focuses on applying one particular neurocognitive theory of learning to physics education.

We discuss two problems in this article:

1. To what extent does the theory of the Five Pillars of the Mind overlap with existing theories of physics education?
2. To what extent are the Five Pillars of the Mind developed in selected learning materials?

The Theory of the Five Pillars of the Mind

The Theory of the Five Pillars of the Mind has been published by Tokuhama-Espinosa (2019). Pillars encompass domain-specific networks in the brain (Tokuhama-Espinosa & Borja, 2023) and explain the holistic functioning of the brain and learning, comprising coherent concepts (Tokuhama-Espinosa, 2019, p. 11). Pillars are comprehensible and complementary to one another. Each of the Five Pillars represents a distinct set of concepts and items that one may learn. Each one of them is further divided into subsets. This division into pillars can be applied to anything one learns at any time, making it relevant to both a pupil and a scientist in any field.

Tokuhama-Espinosa defines Symbols as 'characters used in place of conventional representations to signify meaning, functions, processes, feelings, or objects, including words (Tokuhama-Espinosa, 2019, p.28). It can be divided into three Sub-Pillars: forms, shapes, and representations. There are overlapping areas in the brain that

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correspond to symbolic representations. This fact has been supported by studies conducted by Dehaene (2009). He found that many neuronal mechanisms required for reading are similar to those needed for numeracy skills. Many studies (Krause et al., 2014; Sokolowski et al., 2017; Kovic et al., 2010; Pulvermüller, 2013) have explained how the brain encodes, recalls, recognizes, shapes, and creates symbols such as letters and numbers.

Pattern is another pillar defined by Tokuhama-Espinosa subsequently: 'Patterns are models or recurring designs, or organizational structures used to guide people in completing a task, as in work patterns, school schedules, good (bad) behavior, and other routines' (Tokuhama-Espinosa, 2019, p. 46). This pillar can be divided into four Sub-Pillars: configurations, series, rules, and regularity. There are numerous studies supporting the pillar pattern, where neural networks for pattern recognition (Pavlidis, 2013; Ripley, 2007; Samarasinghe, 2016), rule detection (Osterhout et al., 2012; Ferman & Karni, 2010), musical patterns and dissonance (Abrams, et al., 2010; Salimpoor, at al., 2015) and word and nonword pattern detection (Cappa, 2012; Yoo et al., 2012) are discussed.

Order is essential for learning, as it relies on it, at least in part. Order is another pillar, described as 'the organization or disposition of things or people in relation to each other based on a specific arrangement, method, direction, or structure.' This pillar can be divided into seven Sub-Pillars: sequences, purpose, structure, organization, cycles, and systems thinking (Tokuhama-Espinosa, 2019, pp. 5, 60). Selected studies offering evidence for networks related to order in brain are related to math order (Friedrich & Friederici, 2013; Price, et al., 2013; Tschentscher, & Hauk, 2014), language order (Frengler, et al., 2016; Wang, et al., 2017; Westermann, 2016), event ordering (Demblon, et al., 2016; Mullally, & Maguire, 2014) and to hierarchies and order (Balaguer, et al., 2016; Horikawa, & Kamitani, 2017; Varona, & Rabinovich, 2016).

The fourth pillar is categories, defined by Tokuhama-Espinosa as divisions and classifications of things that share qualities. They are formed based on the qualities and equivalencies of objects, people, places, times, genres, formats, styles, types, concepts, or schema, determined by characteristics or appearances that indicate similarities. Most things in the world can be grouped into multiple categories (Tokuhama-Espinosa, 2019, p. 72). Categories can be divided into three Sub-Pillars: qualities, equivalencies, and classifications. There is also evidence in the literature for category recognition in the brain (Antzoulatos & Miller, 2014; Bergamo & Torresani, 2014; Kemmer, 2017; Murre, 2014).

The fifth and last-mentioned pillar is relationships. Tokuhama-Espinosa defines it subsequently: 'a relationship is the way two or more objects, people, or concepts are connected, related, linked, or associated, or the status of how two or more things are connected' (Tokuhama-Espinosa, 2019, p. 86). This pillar can be divided into eight Sub-Pillars: proportions, correspondence, magnitude, measure, approximation, estimation, quantity, and context. Pillar relationships are also supported by numerous studies, including those by Cozolino (2014), Barth & Paladino (2011), Leibovich et al. (2017), and Libertus (2015). Nowadays, one of the primary goals of Physics education is to foster scientific reasoning abilities (Bao & Koenig, 2019).

Tokuhama – Espinosa (2019) provides three possible implementations of this theory in everyday education: pillars as a teaching method, pillars as a mastery approach, and pillars as a curriculum. Conceptually, pillars are supported by solid evidence, but there is little evidence that this way of organizing learning works in practice. This theory is relatively new and, to the best of our knowledge, has not yet been thoroughly tested; therefore, no definitive conclusion can be drawn at this time. Within our contribution, we chose the first option, which is pillars as methodology. This approach, as explained by Tokuhama–Espinosa (2019), does not require any textbook changes or additional resources. Teachers would make explicit and implicit references, e.g., asking aimed questions about symbols, patterns, order, categories, and relationships within the subject being taught. These references would provide pupils with an opportunity to develop thinking within pillars.

Modeling as Sense-making and Mathematical Modeling in Physics Education

Modeling is an essential part of making sense of the world around us. Physicists attempt to interpret observed phenomena by creating a model, primarily consisting of equations and relationships between variables, which may further predict outcomes under slightly different conditions or initial setups. Modeling in physics education is somewhat different from the everyday work of a scientist. Analyzing data and concluding results in physics requires mathematical components to generate a hypothesis. Mathematization often involves knowledge and skills that are lacking in physics education because of incomplete physics and mathematics curricula.

D. Sands (2021) has proposed a modeling protocol ACME, which guides pupils through building a mathematical model from scratch using a three-stage process. This process begins with assessing the problem, constructing the model, and eventually evaluating it. A key feature of this modeling approach is the capability to transition

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between different representations, starting with sketches or free-body diagrams in the assessment phase, moving to mathematical equations during the construction phase, and ultimately to the representations generated during the evaluation stage. Sands further elaborates on this theory by proposing examples of models, such as teaching sequences and interactive activities (Sands, 2021). Within theories of mental models, mental rules, and reasoning mechanisms, heuristics play a significant role (Tokuhama-Espinosa, 2021). Similar ideas of dual-process reasoning have been intensely discussed in the context of the free-body diagram of a magnet stuck to the vertical side of a refrigerator by Kryjevskaia et al. (2020).

Knowledge in Pieces, Resources-Based theory, Dual Processing theory, and Theory-Theory of Concepts

Other theories of physics education are grounded in cognitive and behavioral sciences, such as Knowledge in Pieces (diSessa, 2018), Dual-Processing theory (Kahneman, 2012), or the Theory-Theory of Concepts (Carey, 1985). We will also discuss Resources-Based theory (Redish, 2004), which elaborates on Knowledge in Pieces and cognitive neuroscience. All these theories aim to explain, in some way, the difficulties pupils face when misinterpreting certain phenomena. Knowledge in Pieces (diSessa, 2018) and Resources-Based theory (Redish, 2004) are very similar. While diSessa (2018) presents phenomenological primitives, also known as p-prims, that are elements of intuitive knowledge, Redish (2004) claims that learners use context-dependent cognitive resources. P-prims allow us to explain or refute real or visualized possibilities. They can be both true and false, as they correctly apply to predict some real outcomes but fail in other circumstances (diSessa, 2018). Redish (2004) refers to elements of knowledge as resources that, when associated, provide the structure of knowledge appropriate to a given situation. Redish (2004) adds to diSessa's (2018) work on p-prims a neuroscientific background of knowledge by grounding learning in this background, meaning that resources are networks of neurons and principles about neurons can similarly apply to resources, e.g.' signals from one or more neurons can result in the activation of linked neurons' and 'activating one knowledge element or resource may lead to the activation of other related resource elements' (Redish, 2004). Central to the resources framework is the notion that thinking is context-dependent, and so is the activation of resources, which essentially refers to how the brain selects among possible neural networks.

Dual Processing theory, summarized in 'Thinking Fast and Slow' (Kahneman, 2012), claims there are two ways of thinking: System 1 and System 2. System one is fast and intuitive, but often leads to misjudgments, whereas system two is slow and analytical. However, reasoning correctly requires a lot of energy and effort; therefore, the brain usually invokes System 1 (heuristics). (Kahneman, 2012) In physics education, pupils often rely on naïve conceptions based on everyday experiences. According to Stanovich (2009), these conceptions are adopted in System 1 thinking, becoming heuristics due to their deeply ingrained nature. However, system two is more often observed within physics education when solving physics problems (Sands, 2013). An important part of Dual Processing theory is cognitive decoupling, which essentially means that one must build a model of a situation that is decoupled from the perception of reality. Sands (2013) elaborates on this aspect in a conference paper, where he discusses gathered evidence for the Dual Processing theory in physics problem solving.

The Theory-Theory of Concepts has roots in psychology and cognitive science. This theory proposes that we all form and revise concepts like those developed by scientists. Keil (1989) defines concepts as follows: 'concepts are partial theories themselves in that they embody explanations of the relations between their constituents, of their origins, and of their relations to other clusters of features'. This means that pupils have intuitive, theory-like frameworks rather than isolated misconceptions. Carey (1985) argued that pupils' naïve theories are structured, coherent, and resistant to change. Carey (2014) stressed the importance of concept acquisition and distinguished between two ways: easy and hard. New concepts efficiently arise from the first encounter with a novel entity. On the other hand, gradually, other concepts emerge over years of exposure and are not achieved by many, despite years of explicit tutoring in school. (Carey, 2014)

Research Results

Overlap between the Theory of the Five Pillars of the Mind and Theories of Physics Education

To apply a new theory to existing theories of any field, one must identify overlaps between new and existing theories. If there are overlaps, the new theory appears promising, and further empirical research should be conducted. With this aim, we identified overlaps between existing theories of physics education—Knowledge in

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Pieces, the Theory-Theory of Concepts, Resources-Based theory, Dual Processing theories, and the ACME protocol, and a relatively new neurocognitive theory of learning, the Five Pillars of the Mind. This theory focuses on education and learning in general. All work on its application to physics education needs to be done by our research team, as we are unaware of any available publications that deal with this research problem. Table 1 provides a comprehensive overview of theories of physics education that we used for comparative analysis of the Theory of Five Pillars of the Mind.

Table 1
Overview of Selected Theories of Physics Education

Theory	Core Idea	Implications for Physics Education
Knowledge in Pieces	Knowledge is fragmented into phenomenological primitives that are shaped by experiences.	A teacher should focus on reorganizing and recruiting. p-prims, rather than on inhibiting misconceptions and connecting intuitive ideas to normative formal knowledge
The Theory-Theory of Concepts	Pupils create coherent mental models similar to physics theories (often scientifically inaccurate)	A teacher should aim for a conceptual change, where naïve ideas are replaced or restructured into coherent, accurate theories.
Resources-Based theory	Knowledge is created based on context-dependent resources	A teacher should instruct pupils in a manner that activates and refines productive resources rather than replacing alternative ideas.
Dual-Processing theory	Pupils' thinking happens either in a fast, intuitive manner or a slow, analytical manner.	A teacher should encourage pupils to think metacognitively, which leads to a shift from intuitive to analytical thinking.
ACME protocol	Pupils create mental models in three steps: assessing the problem, constructing the model, and evaluating the model.	Applying the ACME protocol directly to physics classrooms seems to promote a deeper understanding of physics.

In the Knowledge in Pieces theory, mental models arise by activating phenomenology primitives. Different biases in different pupils are caused by various mental settings (focus of attention, context, and previous experience). We use a model according to our needs. P-prims are not systematically connected to each other, but they tend to be related to patterns in the world (diSessa & Levin, 2018). Within the pillars theory, a learner can understand force as a symbol $\boldsymbol{F}$, especially when considering this concept for the first time. Later, a learner would probably think of force within relationships as a force that accelerates a body or as categories when decomposing forces acting on a body into components. We use pillars according to our needs or contexts. It might seem that both pillars and biases are significantly different from pupil to pupil; however, several researchers on misconceptions and our recent research have shown that alternative ideas are stable, and many pupils consistently hold specific misconceptions (Neidorf, Arora, Erberber, Tsokodayi & Mai, 2019). Similarly, Tokuhama-Espinosa (2019) proposes that, despite the uniqueness of each individual's brain, there appear to be similar networks that all humans use to perform tasks such as reading or math; however, the pathways that create these networks differ from individual to individual. This leads us to suspect that there is also a universal concept-pillar affiliation in a specific context that applies to most pupils in the classroom, similar to how some misconceptions persist among students.

The Theory-Theory of Concepts views concepts as parts of naïve theories that are coherent in a pupil's mind. When new information arrives, it is fitted into these theories; therefore, they are complemented and changed. Pillars are domain-specific networks in the brain of the pupil that have been researched in larger groups of participants. When new information arrives, the brain naturally compares it with what is already known and attempts to integrate the new information within existing knowledge schemes. In both theories, teachers should actively refer to key aspects of these theories. They should identify naïve theories and create cognitive conflicts to revise these theories within the Theory-Theory of concepts, while actively referring to the pillars to strengthen specific networks in the Pillars theory.

The Resources theory claims that resources are networks of neurons (Redish, 2004), and similar principles that apply to neurons apply to resources. The Theory of Five Pillars of the Mind is based on radical neuroconstructivism (Tokuhama-Espinosa & Borja, 2023), and the pillars comprise domain-specific networks of neurons. Pillars are essentially very similar to resources in their neuroscientifically grounded definition; however, resources are not further

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structured as pillars are into symbols, patterns, order, categories, and relationships. Radical neuroconstructivism, among others, claims that brain and cognitive development are interdependent, and the growth of synapses also depends on one's experiences (Westermann et al., 2006). Activation of resources is context-dependent (Redish, 2004), and we presume that identification of concept-pillar affiliation is also context-dependent. The Resources-Based theory and the theory of Five Pillars of the Mind share common core concepts (resources and pillars) and principles. However, the Resources-Based theory was aimed at physics education, whereas the Theory of the Five Pillars of the Mind was aimed at early-age language and math education. The application of the theory of the Five Pillars of the Mind to physics education requires more in-depth research, with an emphasis on both empirical and theoretical studies.

Dual-Processing theory specifically aims to explain reasoning, decision-making, and error patterns in cognition using System 1 and System 2 thinking. The Theory of Five Pillars of the Mind also addresses this phenomenon, focusing on patterns (as one of the pillars) and their role in decision-making. System 1 relies heavily on pattern recognition, and biases arise from this system. Tokuhama-Espinosa and Nelson (2019) explain these cognitive biases as possible results of heuristics or shortcuts that occur in the brain due to its tendency to conserve energy where possible, and heuristics require a low cognitive load. Within the theory of the Five Pillars of the Mind, Tokuhama-Espinosa (2019) proposes that pillar patterns are closely linked to this neurocognitive phenomenon, as our brains naturally seek patterns and familiar elements.

Both pillars and the ACME protocol for modeling consider possible interpretations of information based on previous context or experience. Knowledge is stored and accessed as mental models, and pupils develop different mental models, depending on the circumstances. For example, we have at least three, maybe more, mental models of an electric charge: a point particle with a definite mass subject to classical forces and described by classical mechanics, a wave that can be diffracted, and a quantum entity that has an ill-defined spatial extent and which is described by quantum mechanics (eq Schrodinger's equation). These mental models imply different relationships and interactions with the electron environment, and we use them according to our needs, e.g., in models of electric current, an electron microscope, or electronic states.

Within the ACME modelling protocol, one needs to assess the problem at the beginning, which requires identifying the object (symbols) and its properties (relationships). After evaluating the situation, one constructs the model, which often means translating the mental model into a formal mathematical structure using the detailed knowledge associated with qualitative relationships stored in long-term memory (patterns, and/or order, and/or relationships). Evaluation of the model is the final step in the ACME protocol for modeling, meaning that the model must be run and the obtained data must be compared with real data. Such a comparison can be done using categories and relationships.

The overlap can be well illustrated by discussing the logical errors people commit when confronted with tasks that require logical analysis. Approaching these logical errors through the lens of mental models can be seen as consequences of the mind's limitations when assessing all possibilities. One's mind assesses only several possibilities. Therefore, misinterpretation of information occurs, leading to a logical error. Pillars theory also considers such errors, mainly connected to patterns. Bias in a pupil's mind can be discussed through heuristics. Heuristic shortcuts help pupils make decisions and judgments quickly without spending much time researching and analyzing information. Heuristics are also closely connected to patterns and play a crucial role in problem-solving. According to the pillars theory, analogy appears to be an efficient teaching method, as patterns influence the speed of one's thinking and decision-making. New information is being transferred to the brain through neural networks. It is being compared with what one already knows. The brain naturally looks for what it already knows, essentially patterns that shorten the time needed to transfer a neural impulse.

Table 2 provides a summary of the identified overlaps between selected theories of physics education and the theory of the Five Pillars of the Mind. Several theories discussed cognitive errors and explained their origin using different terminology, but essentially, they all overlapped with the pattern recognition and the brain's tendency to economize decision-making. Learning, however, occurs when heuristics are avoided. The five pillars of the Mind essentially overlap with all the theories. However, the two theories that overlap the most in physics education are the Resources-Based theory and the ACME protocol. Resources seem very similar in definition to pillars; however, they are not the same. The ACME protocol is the newest of these theories and reflects many of the mentioned theories; therefore, the overlap is significant.

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Table 2
Identified Overlaps of Selected Theories of Physics Education with the Theory of the Five Pillars of the Mind

Theory	Overlaps with the theory of the Five Pillars of the Mind
Knowledge in Pieces	Context dependency, possible generalization, and patterns in the world
The Theory-Theory of Concepts	Fitting new knowledge into existing models, explicitly working with key aspects
Resources-Based theory	Conceptually, common core concepts and principles
Dual-Processing theory	Decision making, cognitive errors
ACME protocol	Overlaps with specific pillars at each step of the ACME protocol, cognitive errors

Textbooks Analysis and Pillars Identification

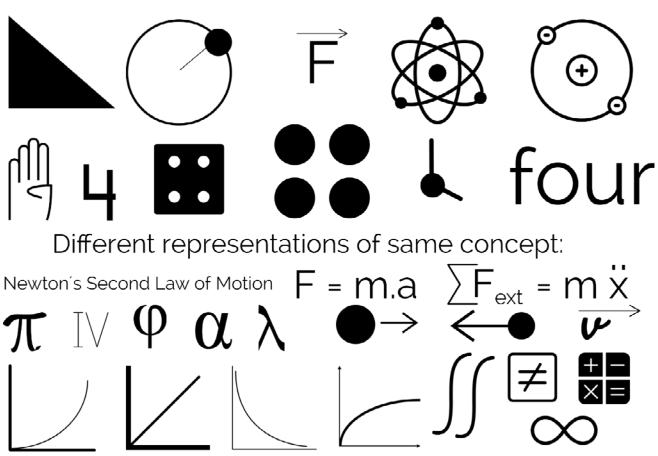
The focus is on applying the theory of the Five Pillars of the Mind to the theory of physics education. Since the theory of the Five Pillars of the Mind has not yet been presented within physics education, we identified examples of each pillar in physics contexts. The identification of physics examples for each pillar was conducted in several steps and informed by an analysis of selected sections from physics textbooks. Firstly, a topic inclined plane has been chosen, and all the necessary knowledge and skills a physics graduate should have within this topic at the end of higher secondary education have been addressed based on the Slovak national requirements for higher education graduates (ŠPÚ, 2019). Secondly, we selected several physics textbooks to identify key concepts developed in the analyzed textbooks. For each concept, a pillar was allocated based on the context in the analyzed textbooks. We defined selection criteria for textbook analysis as follows:

1. Alignment with national requirements for higher education physics graduates;
2. Market usage of textbooks;
3. Similarity of pedagogical approach.

Selected textbooks Duncan & Kennett (2014), Morris (2015), Reynolds (2013), Koubek et al. (2009), and Lapitková et al. (2012) all discuss prerequisites and selected topics. They were chosen because they align with the Slovak national requirements. Koubek et al. (2009) and Lapitková et al. (2012) are widely used in Slovakia and approved by the Ministry of Education. Duncan & Kennett (2014), Morris (2015), and Reynolds (2013) are widely used in general and within selected topics, aligning with national requirements.

The analysis and identification were conducted individually by two researchers, who coded selected parts of the listed textbooks. The agreement rate among researchers was 86%, and the final dataset reflected the agreed-upon content in the discussion. Analyzing four series of physics textbooks led to identifying examples of each pillar concerning physics topics. Here are listed typical examples from Physics, and later, we focus on the topic of the Inclined Plane. Figure 1 displays examples of symbols (forms, shapes, representations) in physics education.

Figure 1
Example of Symbols in Physics Education



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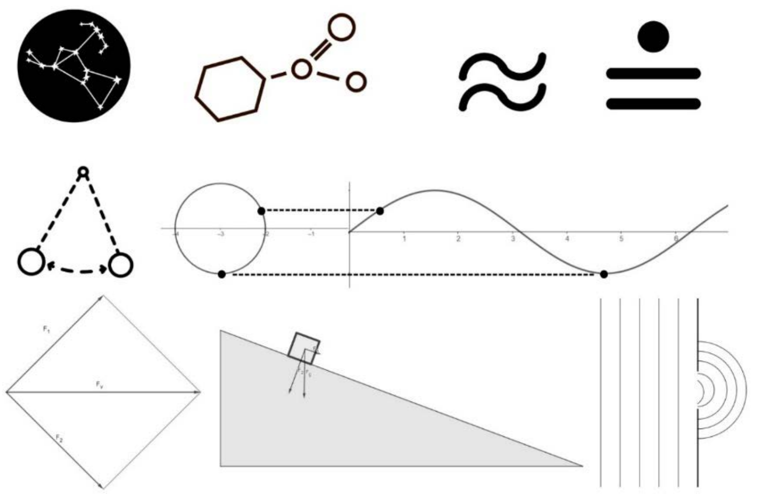
A right-angled triangle is typically used to represent the inclined plane. Right next to it is a basic representation of circular motion. F is a symbol and vector representation of force. The last two symbols in the first row illustrate atomic structure and electron orbitals. The second row has six representations of four: a number, a word, and a gesture. The same principle applies to the next row, which shows different representations of Newton's Second Law of Motion. This law itself would be included in the pillar relationships, but we illustrate that relationships are also represented, and these representations can differ, yet still describe the same phenomenon. Greek alphabet letters are commonly used to represent physical quantities or constants. Roman numerals are used in physics, too, for example, to denote various states of an ideal gas. Differences can express different weights of objects and differences in their velocities in the size (to scale or not to scale) of corresponding representations. Graphs are helpful tools not only in physics but also in other fields because they store large amounts of data, indicate correlations between variables, and show trends. Graphs are also used to define quantities, such as density, in physics in lower secondary schools. A linear function is the most accessible to pupils, who usually show little or no difficulty understanding.

On the other hand, an exponential function occurs within many physics concepts and draws the attention of many physics educators. Mathematics can be considered a universal language, with its symbols essential for physics. It enables physicists to shorten their ideas into equations. Mathematical signs and figures, together, create a fundamental group of symbols for Physics education.

Figure 2 demonstrates examples of patterns (configurations, series, rules, regularity) in physics education that we identified.

Figure 2
Example of Patterns in Physics Education



Configurations are patterns, e.g., a constellation or arrangement of atoms within a molecule. Series also belong to patterns and function series, such as the Fourier series, which are commonly used in Physics to represent periodic functions as a sum of sine and cosine functions. For instance, when an oscillating system is driven by a periodic force external to the oscillating system, applying the Fourier series seems essential to solve a differential equation of motion. Obviously, this is not a part of core Physics education courses in secondary school. Rules, such as how to round up numbers, how to write a result of a Physics problem in scientific notation, how to find the vector sum of forces acting on an object, or how to break down forces in space, belong to patterns. Diffraction grids, as well as pendulums, can be treated in the mind of a pupil as patterns. The pendulum shows a pattern in the movement of a weight, which can be associated with circular motion.

Examples of **order** (sequences, purpose, structure, organization, cycles, systems thinking) in Physics and Physics education are shown in Figure 3.

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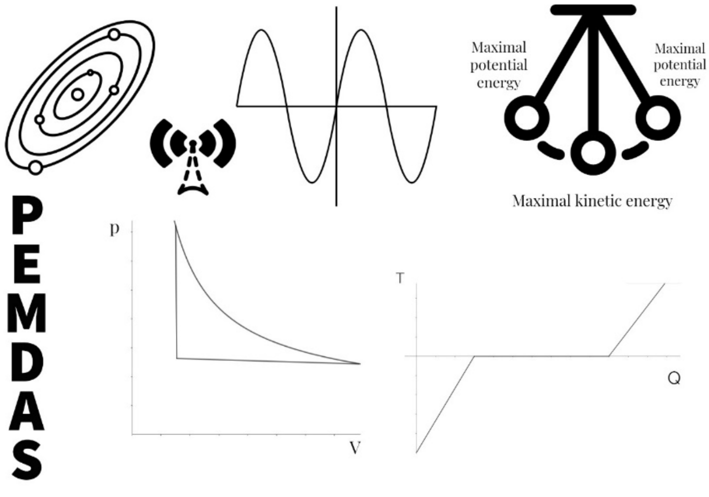
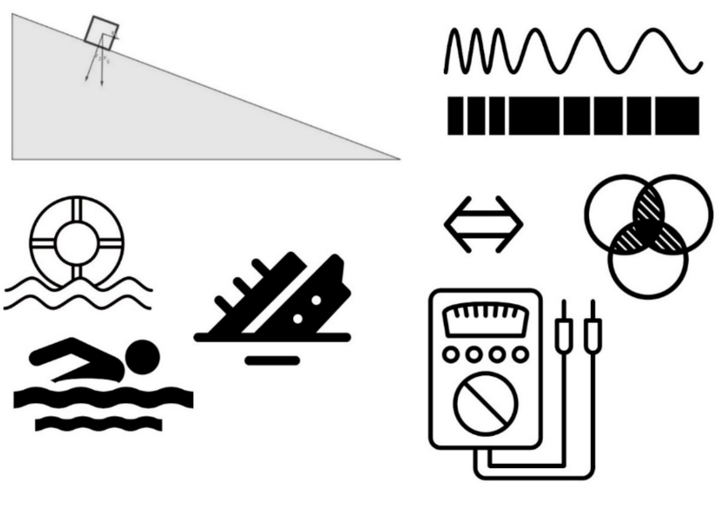
Figure 3
Examples of Order in Physics



In space, planets are arranged in order of distance from the sun. A rule in mathematics for solving equations is PEMDAS (Parenthesis, Exponents, Multiplication, Division, Addition, Subtraction), which expresses the order in which mathematical operations should be performed. A sequence can be observed in the way water changes phases. These changes are illustrated on a graph on the right, indicating that the ice temperature increases, and then the added heat is used to change the water. After this phase, the temperature of the water increases as the added heat increases. The mechanical energy of an object changes in sequences, as illustrated by a pendulum. The cycle is represented by a graph on the left, illustrating the different stages of an ideal gas that undergoes a finite number of processes, such as isothermal processes. Another example of a cycle is a periodic function that delineates the displacement of a wave in time.

Identified examples of **categories** (qualities, equivalencies, classifications) in physics are displayed in Figure 4.

Figure 4
Examples of Categories in Physics



Using a free-body diagram and resolving forces into independent components at right angles to each other can be considered a method of classifying forces, or rather their components, based on their direction. Categorization of items can be accomplished by comparing their qualities. This way, we can categorize objects based on their ability to sink, swim, or float in water; categorize electromagnetic waves by their wavelengths; or categorize

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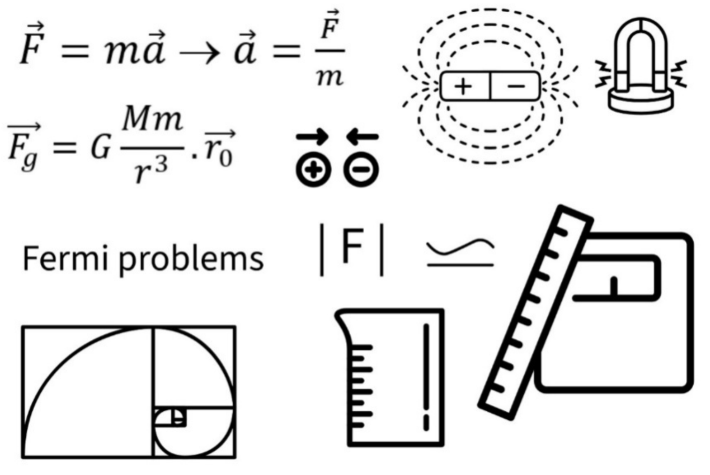
objects by their ability to conduct current. Equivalences also express categories, and Venn diagrams display similarities and differences.

Figure 5 shows examples of relationships (correspondence, magnitude, measure, approximation, estimation, quantity, and context) in Physics.

Figure 5
Examples of Relationships in Physics



The relationship can express dependence between two variables. The golden ratio occurs naturally in the world. It is defined as a relationship where two quantities are in the golden ratio if their ratio matches the ratio of their sum to the larger of the two quantities. Relationships also include pupils' abilities to measure precisely and accurately, depending on the chosen method, as they need to determine the uncertainty of their measurement. Relationships are also present in pupils' ability to estimate the outcomes and make approximations. The Fermi problems are well-known estimations that scientists often use to find approximate solutions before employing more time-consuming methods to calculate precise answers. This helps them distinguish an incorrect hypothesis more quickly. Interaction between two objects, such as charged particles, is also an example of a relationship.

Proposal of Application of the Theory of the Five Pillars of the Mind into Physics Education Using a Modeling Activity, Inclined Plane

As mentioned in the Research methodology, we analyzed the development of concepts and the skills pupils need to solve advanced problems concerning the inclined plane in four series of textbooks, both Slovak and English. Then, we incorporated approaches from various textbooks and proposed a design for developing concepts related to the inclined plane. Within this process, we mainly focused on identifying pillars that could be promoted when discussing a specific concept.

Table 2 presents this proposal, showcasing key concepts that can be developed within some or several pillars at the stated age of the learner. At the age of 9-11 years, pupils often assign a scientific name to a phenomenon they have already encountered in their lives; therefore, most of the concepts developed are most likely connected to symbols. Pupils might, however, categorize phenomena or learn how they are interconnected, thereby learning about categories and relationships. Further on, pupils learn more about relationships and patterns in known concepts.

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Table 2
An Example of a Design for Developing Concepts Related to the Topic of an Inclined Plane

Key concept	Age	Identified Pillar
Inclined plane as a simple machine	9 - 10	Symbols
Mutual interaction between two bodies –graphic representation	11	Symbols
Mutual interaction between two bodies – types of forces	11	Categories
Mutual interaction between two bodies –resultant force	11	Relationships and/or Patterns
Frictional force and friction	11	Symbols and/or Categories
Circular motion and centripetal force	11	Symbols
Energy – forms and sources of energy, their conversion, use, and energy storage	11	Symbols and/or Categories and/or Patterns, and/or Order
Kinematics – path, speed, velocity, and acceleration	12 - 13	Symbols and/or Patterns and/or Relationships
Rigid-body dynamics - center of mass, torque (defined verbally)	13	Symbols
The net force - vector sum of forces acting in one plane	14	Relationships and/or Patterns
Newton's Laws of Motion	14	Relationships
Torque, center of gravity – physics equations	14	Order and/or Relationships
Mechanical energy, the principle of conservation of mechanical energy	14	Order and/or Relationships
Moment of inertia	16	Order and/or Relationships and/or Categories

This proposal aims to demonstrate a method for working with pillars at the methodological level. A teacher could examine the concepts being discussed and assign the pillars being promoted. Such an analysis of a lesson could provide insights into the distribution of time spent on different pillars. In physics education, most of the time is likely spent on symbols and relationships. However, Tokuhama-Espinosa (2019) claims that all five pillars, or as many as possible, should be discussed and presented to economize learning. However, it is crucial to note that not all pillars necessarily need to be promoted in a single learning-teaching sequence.

Limitations

The discussion should focus on how a physicist might perceive pillars and the uncertainties that might arise when applying them in physics education. Symbols are used to convey meaning, and precisely how this occurs is still open to debate, but this puts symbols into a different category from the other pillars. Even diagrams representing categories and patterns use symbols to convey meaning, and herein lies one of the difficulties. The symbol represents two possible meanings: the one intended by the author and the one actually understood by the reviewer. These will not necessarily be the same. For example, we can see a symbol representing an inclined plane in both the patterns, Figure 2, and the categories, Figure 4. However, we might not know what pattern or category these are intended to represent without further explanation.

A physicist does not organize their understanding of physics into categories of problems, but novices do, and the inclined plane might represent a category of problem with its own rules. Novices tend to categorize problems based on surface features, explicitly mentioning the inclined plane in this regard. Experts, on the other hand, analyze problems based on the principles involved, and it is well known that an expert problem solver spends time understanding the problem before moving on to the solution.

This, then, might seem to be a weakness of the Five Pillars model. Patterns, Categories, and Order are ways of organizing information. They might well be important, and there are clearly recognized categories, such as hadrons, leptons, and groups in the periodic table, among others. The established theory of concepts is that these are categories. Patterns are also essential, and it is our understanding that awareness of patterns in pre-schoolers is essential to later mathematical development. There is evidence that such awareness can be taught. However,

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the willingness or ability to see patterns where none exist is also a feature of conspiracy theorists. This implies to us that care is needed. Shoe-horning physics problems into categories to which specific rules apply is ultimately not productive unless it serves as a stage to a more advanced understanding, and creating patterns where none exist is unproductive. However, attempts to represent these things by symbols, as has been done in figures 2-4, suffer from the difficulty that the symbol might not evoke the same idea in the beholder, who, in consequence, might not agree. This undermines acceptance of the theory. In physics, order is frequently used to imply a spatial arrangement, but that overlaps with "patterns". This is a potential source of confusion and needs to be clarified.

That leaves relationships, and one can argue that what we understand as concepts in physics are, in fact, qualitative relationships. These are the building blocks of our understanding, which we use to reason qualitatively about the world. We can also reason with patterns and categories, but one suspects the circumstances are quite specific to certain types of problems. To this point, this is up for discussion; however, the process of modeling and the relationships involved here are very important. It seems to us, then, that symbols are probably paramount in that they convey meaning. They invoke models of relationships, processes, patterns, categories, etc., but the meaning they convey is not necessarily the meaning intended by the author of the symbol. We use relationships to reason about the world, making these two —symbols and relationships —the most important of the Five Pillars.

To compare this result with the author's definition of pillars, pillars are categories of domain-specific networks that do not have a hierarchy within them (Tokuhama-Espinosa, 2019, p. 20). However, this might vary across different fields of study when applying them. Within our research, we have also found that in most physics textbooks, both Slovak and international, symbols and relationships are mainly being developed (Červeňová & Demkanin, 2025). To resolve the hierarchy issue between pillars in physics education, we are planning to use LLM to identify pillars within developed physics concepts and are conducting broader qualitative research, where we use the Grounded theory method (Charmaz, 2024).

Conclusions and Implications

This theoretical research concludes that the Theory of the Five Pillars of the Mind would allow us to estimate the neural representations of the individual pillars, which would then enable us to design a series of educational activities in such a way that a teacher optimally stimulates the necessary neural pathways, thereby making the student's learning more effective. This would allow a review of currently existing science curricula. According to the assumptions stated above, our analysis of the development of concepts related to the topic of inclined plane can be considered an example of an analysis of a physics topic from the perspective of the Five Pillars of the Mind. Subsequently, based on identified pillars, it is possible to use the afterwards design of a series of educational activities so that the development of the necessary concepts takes place effectively and meaningfully for the pupil. We proposed a design for developing concepts related to the topic of inclined planes and discussed how pillars might be suitable for physics education.

Based on this preliminary study, it can be concluded that systematic attempts to create models of mind, grounded in a bio-psycho-social view of students, can be applied to the theoretical background of physics education. Moreover, it can be observed that these theories significantly overlap with existing theories of physics education, which can be refined and enriched by evidence-based models.

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Declaration of Interest

The authors declare no competing interest.

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